OSIRIS-REx:

NASA's Asteroid Sample Return Mission

New Frontiers 3

Ron Perison

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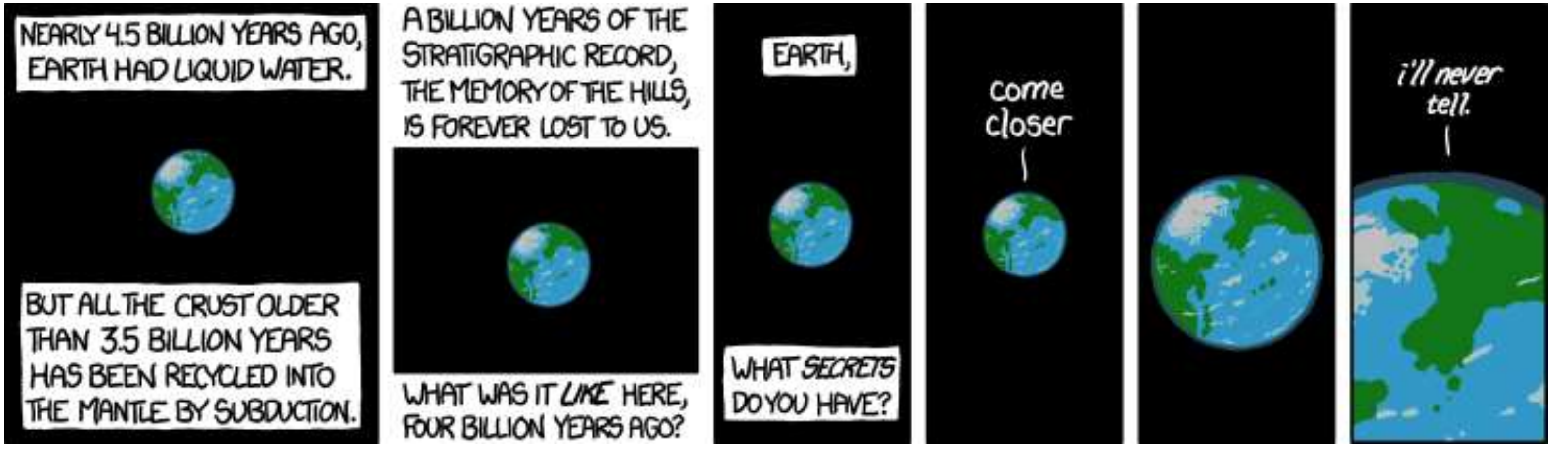
Project Scientist

NASA Goddard

http://www.asteroidmission.org/movie/

The Ancient Earth



"All we have are these stupid tantalizing zircons and the scars on the face of the Moon."

- Earth was bombarded during and shortly after accretion by **asteroids and comets**.
- The **record** of the origin of the Earth and of the origin of life has **been destroyed** by geologic processes.
- Meteorites tell us that these bodies **delivered water and organics** to the early Earth.
- Meteorites are **not well connected** to their parent and **quickly become contaminated**.

https://xkcd.com/1194/

EXTRATERRESTRIAL SAMPLES

Scott Messenger and Danny Glavin collecting a meteorite. Dante Lauretta (background) searching with a metal detector.

http://caslabs.case.edu/ansmet/

SAMPLE RETURN MISSIONS: THE GIFT THAT KEEPS ON GIVING

- Moon (1969-72, 1976)
  - NASA Apollo 11, 12, 14, 15, 16, and 17
  - Soviet Luna 16, 20, and 24
- Solar wind (returned 2004)
  - NASA Genesis
- Comet tail (returned 2006)
  - NASA Stardust
- Stony Asteroid (returned 2010)
  - JAXA Hayabusa
- Carbonaceous Asteroid
  - JAXA Hayabusa2 (launch 12/14)
  - NASA OSIRIS-REx (launch 9/16)

State-of-the-Art Analytical Instruments Cannot Be Flown on Spacecraft

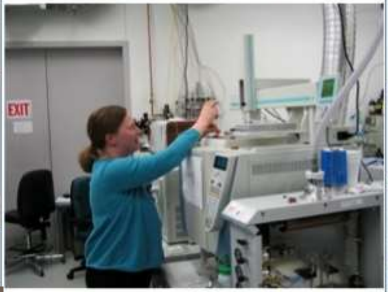
Mineralogy & Petrology	Elements & Isotopes	Organics	Spectroscopy	Thermal
Understanding Asteroid History	Understanding Solar System History	Detecting the Molecules of Life	Linking Asteroids to Meteorites	Understanding the Yarkovsky Effect

NanoSIMS

Electron Microprobes

FIB

LA-ICP-MS



GC-MS/c-IRMS

TOF-SIMS

LC-FT-MS

LC-TOF-MS

GC-MS

FE-STEM

IR Microscope

FT-IR

SEM

Future Scientists will Invent New Instruments

Accelerator Mass Spectrometer

ALS Synchrotron Beamline for XANES

THERE ARE A LOT OF ASTEROIDS

Running Tallies

10/15/16

Near-Earth Objects Discovered

THIS MONTH:	108
THIS YEAR:	1484
ALL TIME:	15098

Minor Planets Discovered

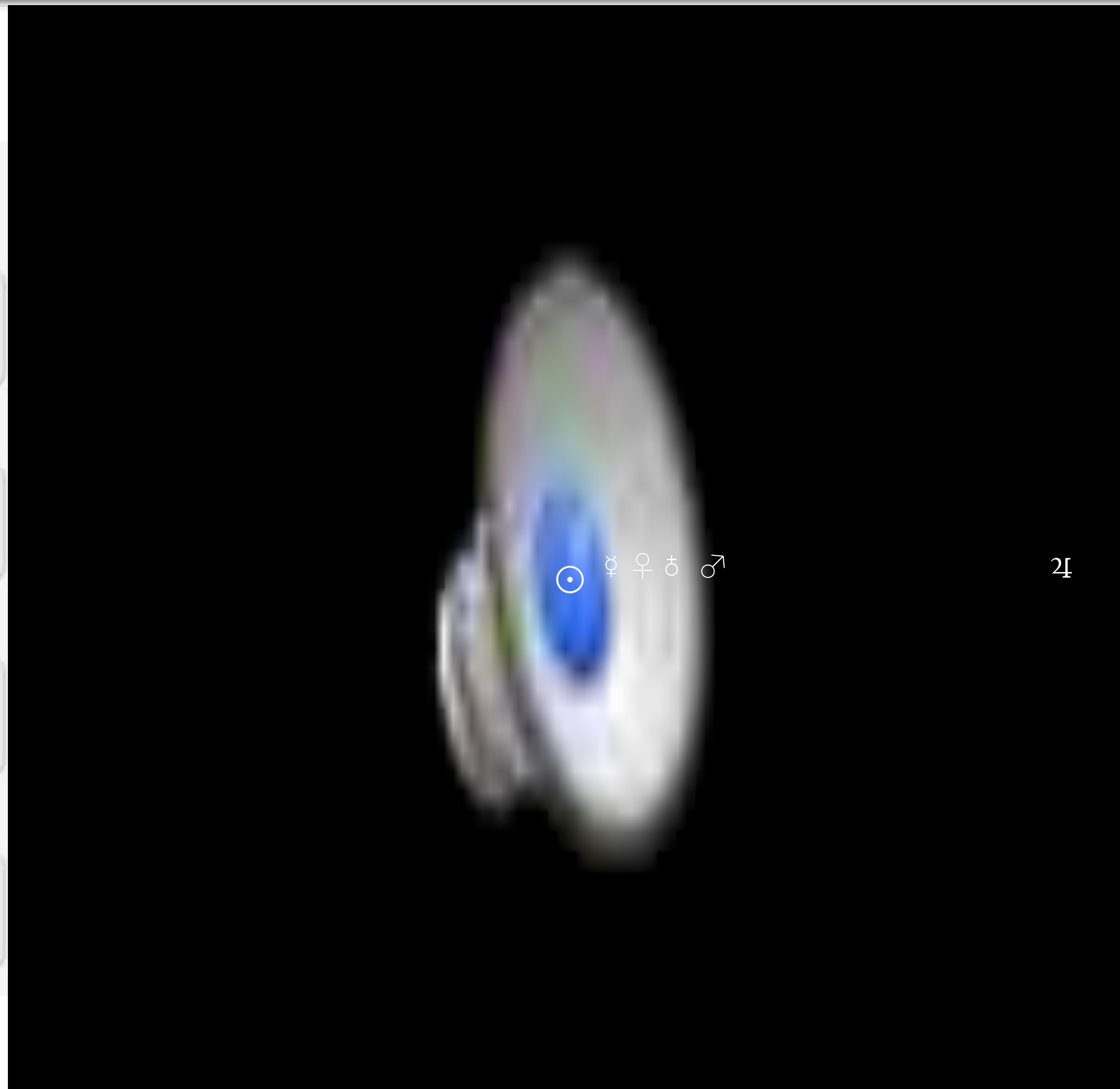
THIS MONTH:	2289
THIS YEAR:	40431
ALL TIME:	717768

Comets Discovered

THIS MONTH:	2
THIS YEAR:	38
ALL TIME:	3951

Observations

THIS MONTH:	798704
THIS YEAR:	14.2 million
ALL TIME:	155.7 million

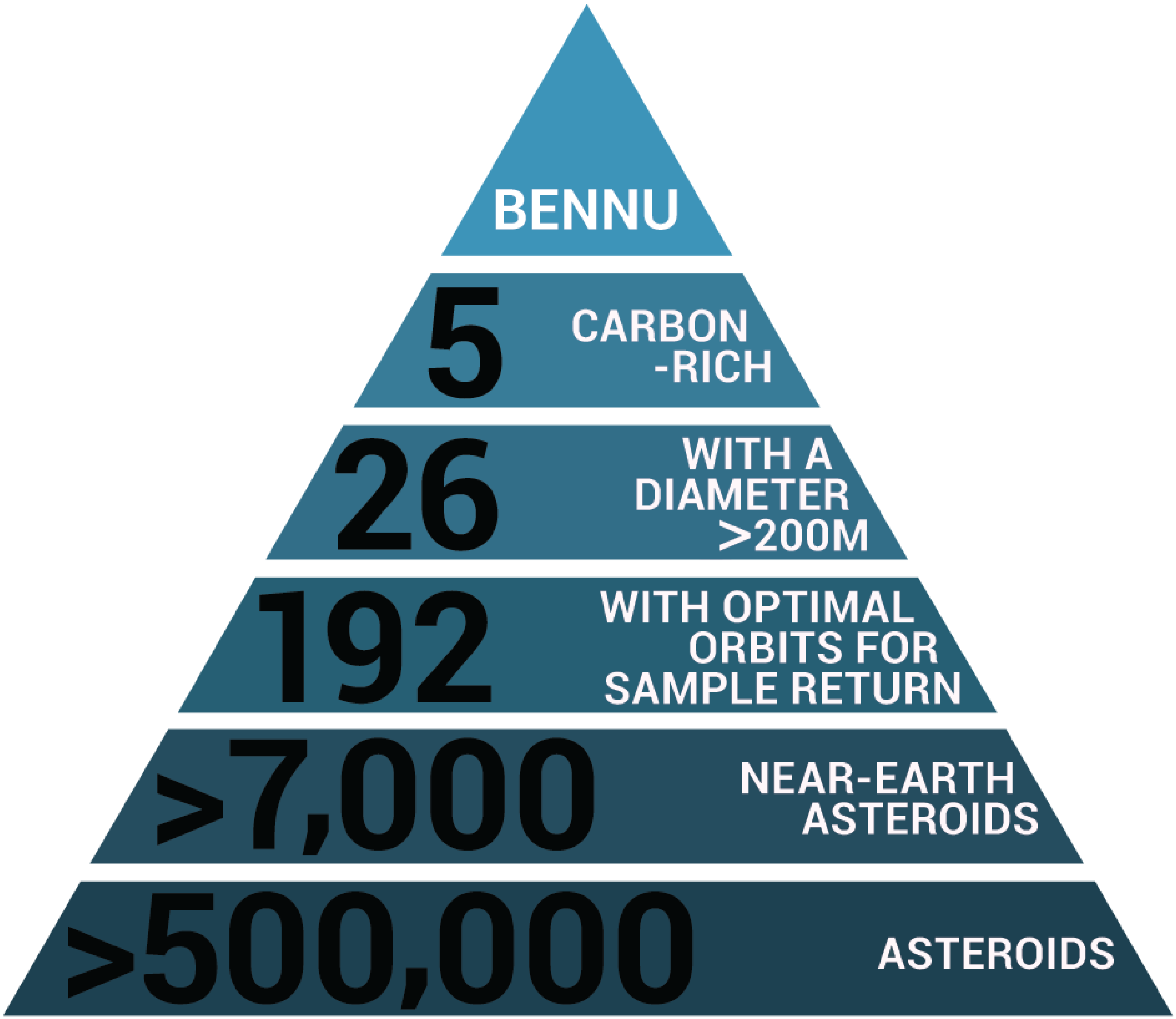


http://www.minorplanetcenter.net/

Near Earth
Main belt
Jupiter Trojan

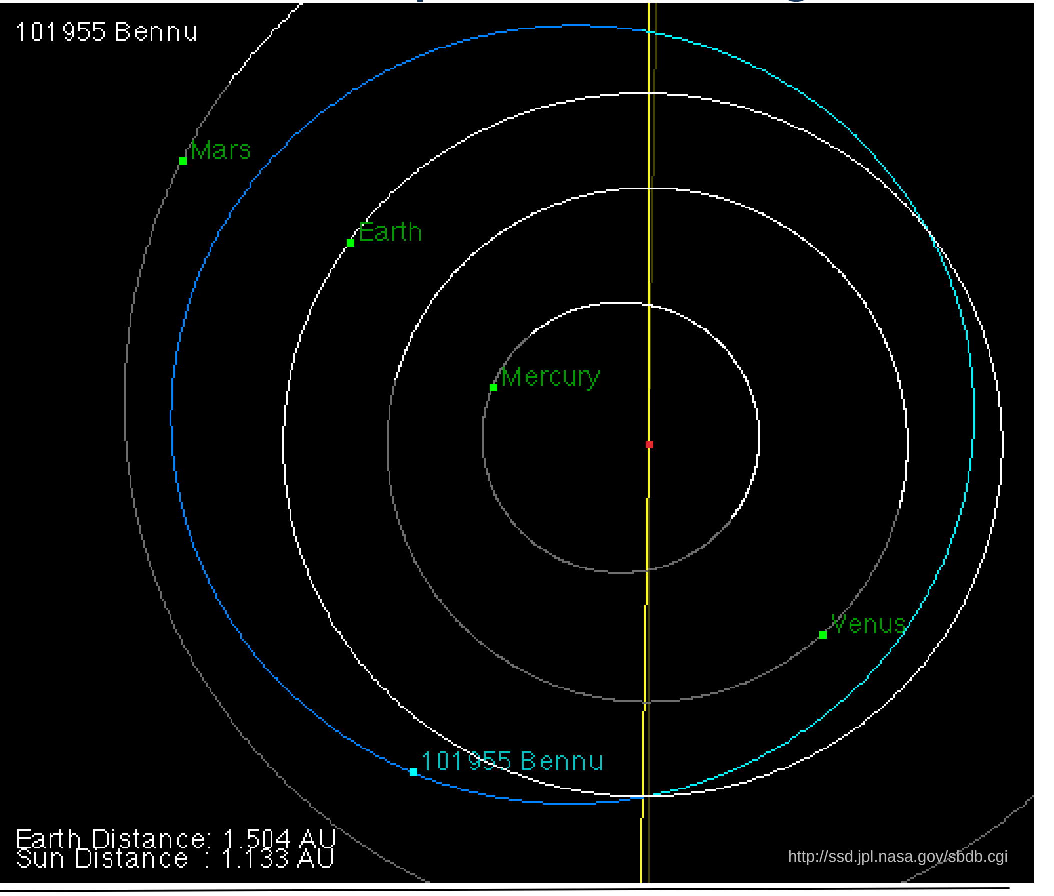
Some Have Been Visited

But Only One Is Ideal

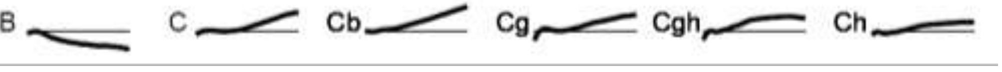


BENNU IS AN EXCELLENT TARGET

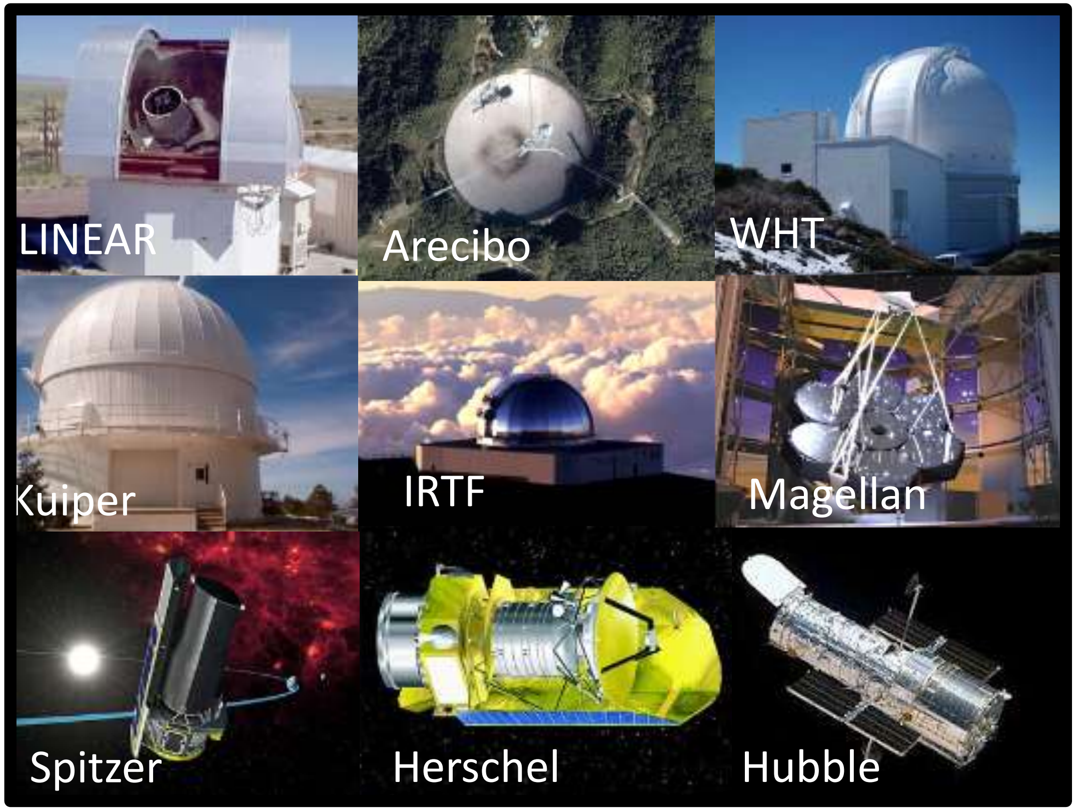
- **Very low albedo**, 4% and **low density**, 1 g/cc.
- **Organic-rich meteorites** are the best spectral analogs.
- There is strong evidence for **loose rocks** (regolith) for collection.
- The **orbital parameters** are well characterized.
- **Potentially Hazardous** (1:2700 chance of impacting in the late 22nd century) Asteroid.

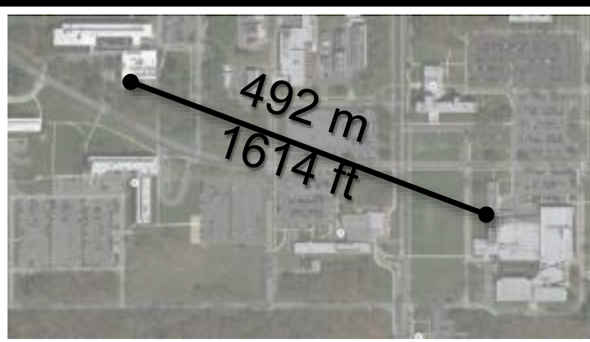


*Some asteroid spectral classifications (440-920 nm):



BENNU IS EXTENSIVELY CHARACTERIZED

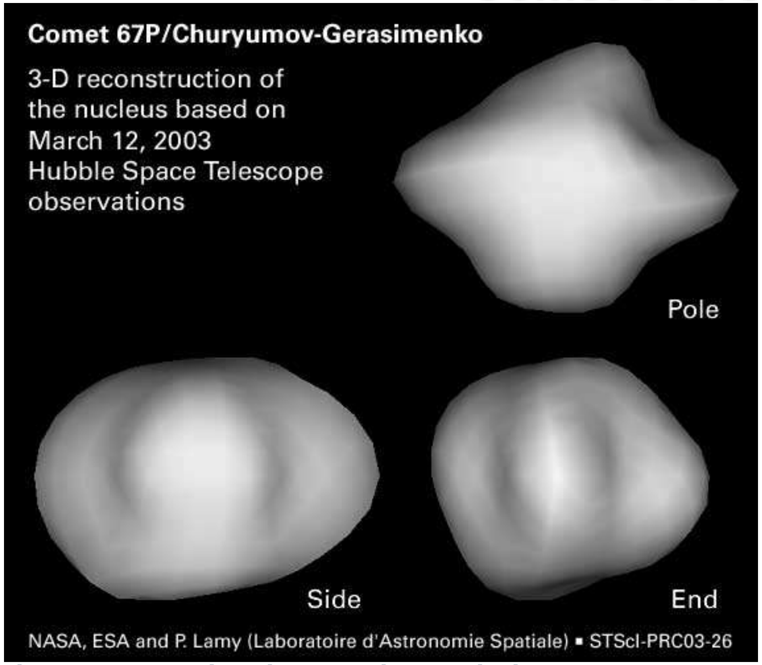




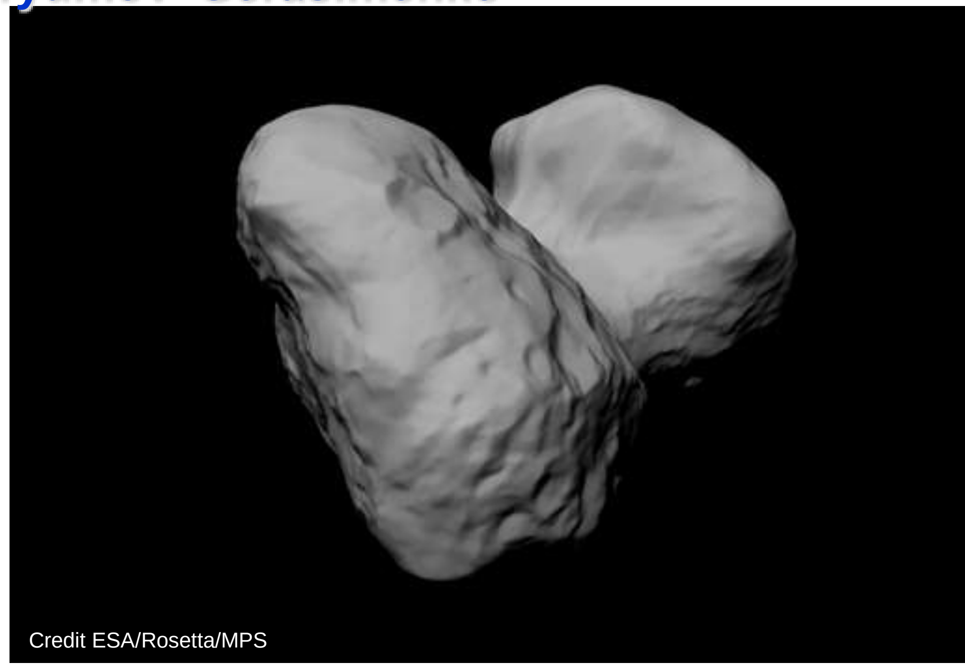
- **Discovered** on Sept. 11, 1999 by the LINEAR survey
- **Observed** with the Arecibo Planetary Radar system in Sept. 1999 and Sept. and Oct. 2005 (also with Goldstone)
- **Observed** with the Kuiper 1.5-m telescope multiple times in Sept., Oct. 2005, Sept. 2011
- **Observed** with the NASA Infrared Telescope Facility in Sept. 1999, Sept. 2005, and August 2011
- **Observed** with the Spitzer Space Telescope between May 2007
- **Observed** with the Herschel Space Observatory, Giant Magellan Telescope, and WHT in Sept. 2011
- **Observed** with Hubble and Sptizer August and Sept. 2012

CHARACTERIZATION GREATLY LOWERS RISK

Comet 67P/Churyumov–Gerasimenko

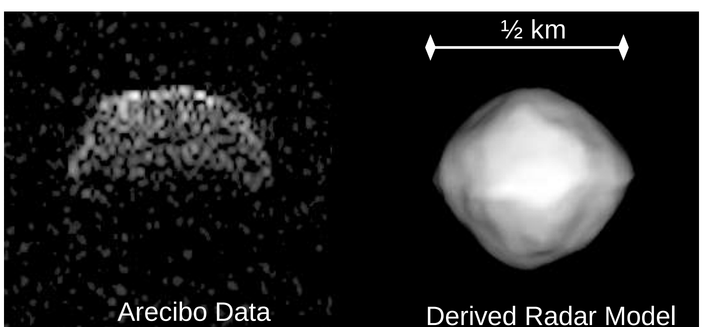


Shape model based on light curve only (no radar data)



Actual Shape

Asteroid 101955 Bennu



Radar shape model

Expected to be close to the radar model

Actual Shape

Who is OSIRIS-REx?

Principal Investigator: Dante Lauretta (UA)
Deputy PI: Edward Beshore (UA)
First PI: Mike Drake (UA, deceased)
Project Manager: Mike Donnelly (GSFC)
Flight System Manager: Rich Kuhns (LM)

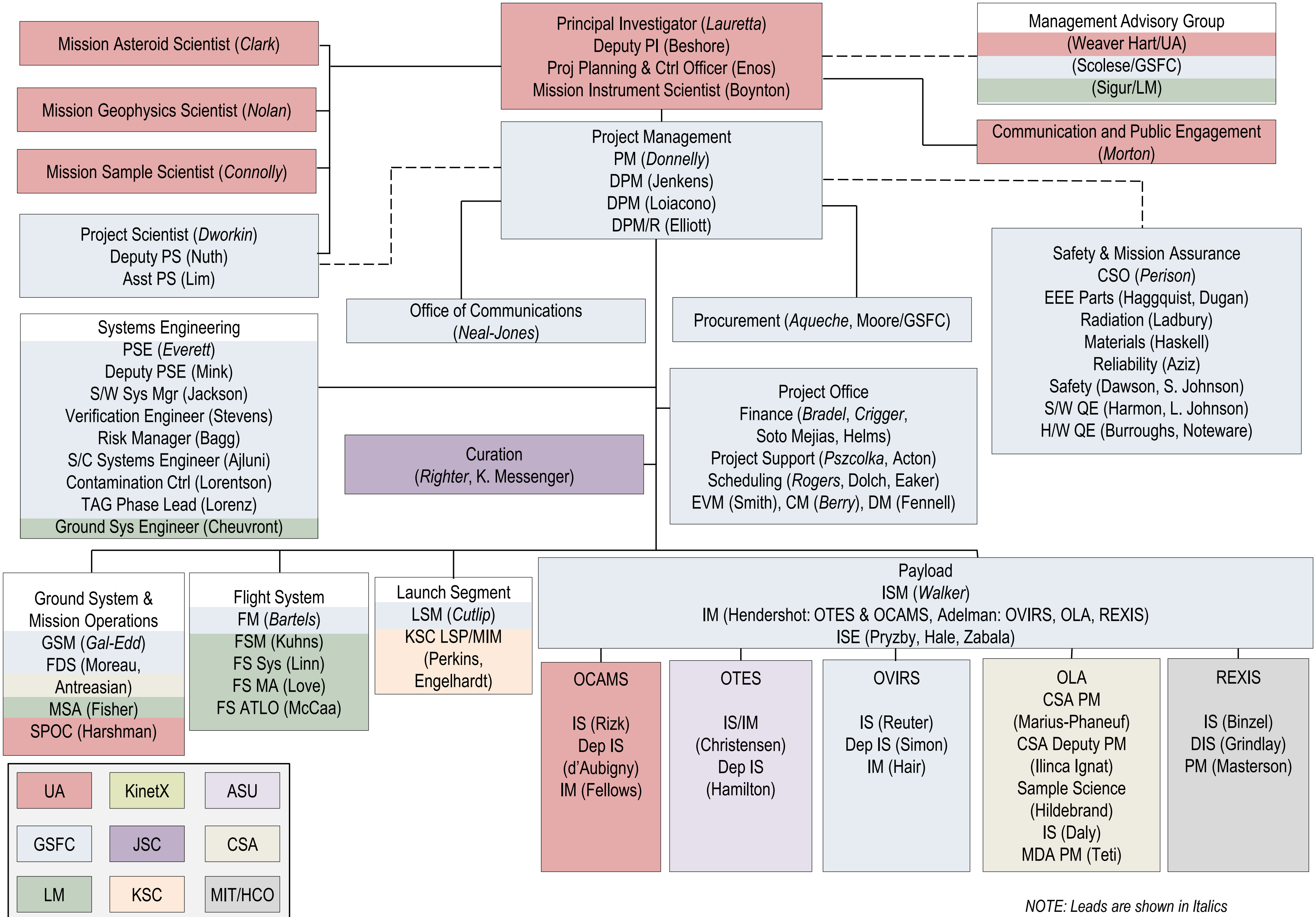
Lockheed Martin Space Systems
- Flight System
- Sampling System
- Sample Return Capsule
- Mission Operations

Canadian Space Agency – OSIRIS-REx Laser Altimeter (OLA)
Arizona State University – OSIRIS-REx Thermal Emission Spectrometer (OTES)
KinetX – Navigation/Flight Dynamics
Johnson Space Center – Sample Curation
Indigo Information Services – PDS Archiving

University of Arizona
- Principal Investigator & Deputy PI
- Project Planning and Control Officer
- Mission Instrument Scientist
- Science Team Management
- OSIRIS-REx CAMera Suite (OCAMS)
- Science Processing and Operations Center (SPOC)
- Data Management and Archiving
- Community and Public Engagement

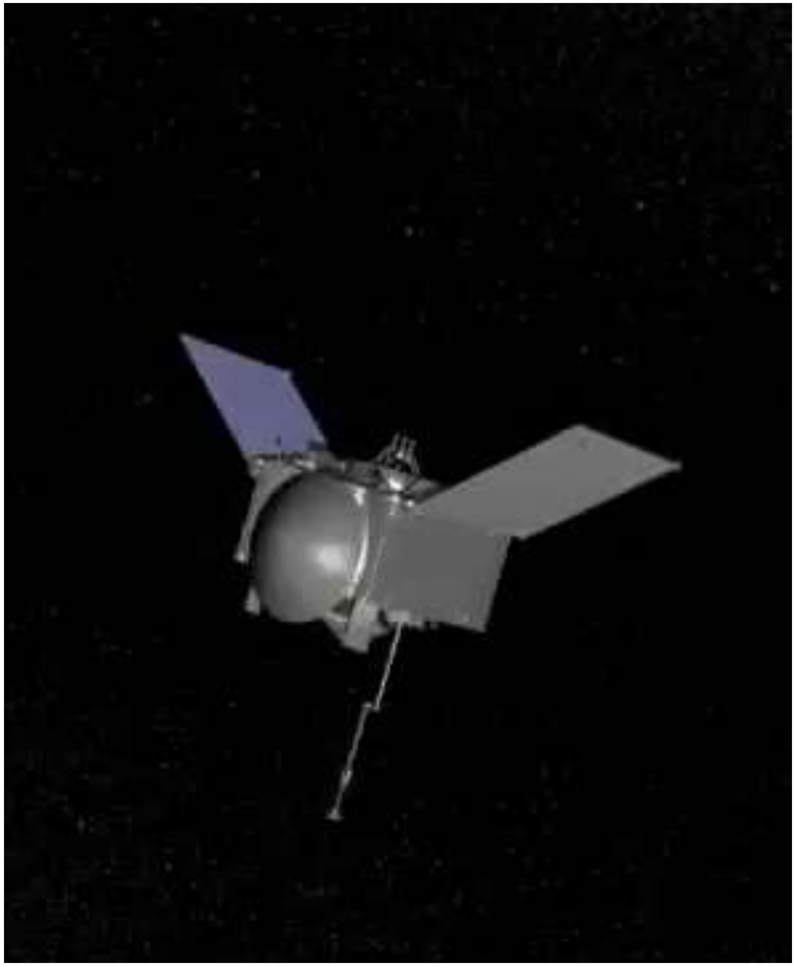
NASA Goddard Space Flight Center
- Project Management
- Project Scientist & Deputy Project Scientists
- Mission Systems Engineering
- Safety & Mission Assurance
- OSIRIS-REx Visible and near Infrared Spectrometer (OVIRS)
- Flight Dynamics Lead

OSIRIS-REx Project Organization (C/D)



NOTE: Leads are shown in Italics

What is OSIRIS-REx?



Origins

- Return and analyze a sample of pristine carbonaceous asteroid regolith

Spectral Interpretation

- Provide ground truth for telescopic data of the entire asteroid population

Resource Identification

- Map the chemistry and mineralogy of a primitive carbonaceous asteroid

Security

- Measure the Yarkovsky effect on a potentially hazardous asteroid

Regolith Explorer

- Document the regolith at the sampling site at scales down to the sub-cm

Mission Objectives

1. Return and Analyze a Sample

2. Provide Sample Context

3. Understand Asteroid Geology, Dynamics, and Spectroscopy

4. Understand the Interaction Between Asteroid Thermal Properties and Dynamics

5. Improve Asteroid Astronomy

Mission Objectives

1. Return and Analyze a Sample

- The sample must be kept pristine for modern lab analyses.

2. Provide Sample Context

3. Understand Asteroid Geology, Dynamics, and Spectroscopy

4. Understand the Interaction Between Asteroid Thermal Properties and Dynamics

5. Improve Asteroid Astronomy

Defining Pristine

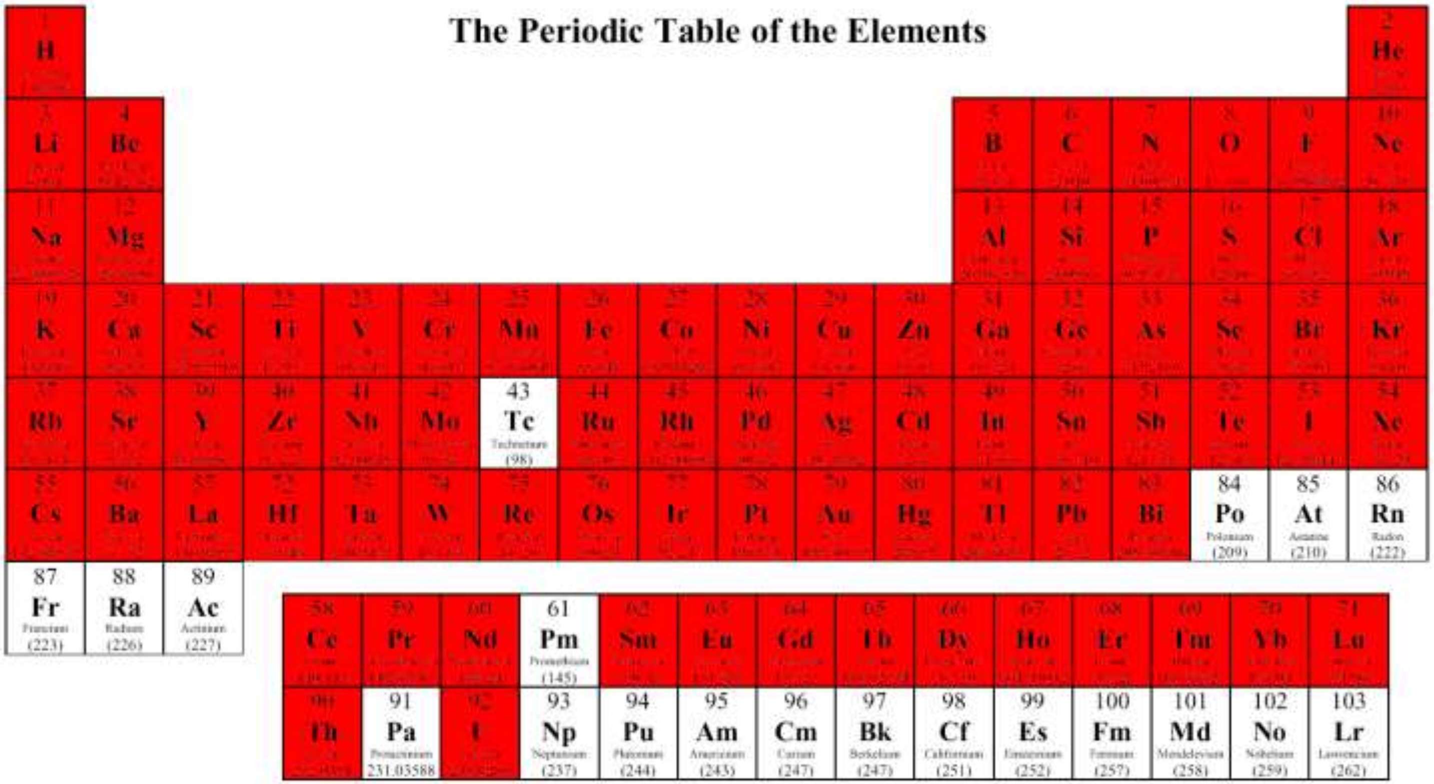
- **Totally clean is impossible**
  - In the strictest sense contamination is any alteration of the physical, chemical, textural, or other sample state that compromises sample integrity.
  - Alteration includes changing inherent states, losing sample components, or adding extraneous components,
    - e.g. changes in bulk chemistry/mineralogy, trace components, stable isotopic ratios, volatiles (ices, organics), crystallinity and phase state, remnant magnetism, grain-size distribution, grain/clast integrity, texture/structure/layering, and chemical/electronic activation state.
  - ***Our focus is on the addition of organics, isotopes, and trace elements***

- **Contamination of the sample can occur at any time and mitigation needs to be planned from day 1**
  - Thus, there is no point being cleaner than conditions of curation

- **The spacecraft still has to work, so contamination can be relaxed under contingency via graceful descopes**
  - A contaminated sample is better than a failed mission

SPECIES OF SCIENTIFIC INTEREST

Inorganic



Organic

- Aliphatics (R-CH)
- Amides ($R\text{-}CONR_2$)
- Amines ($R\text{-}NR_3$)
- Aromatics ($[C{=}R\text{-}R]_c$)
- Carbonyls (R-COR)
- Hydroxyls (R_3COH)
- Amino acids
- DNA

Drivers for Contamination Control (CC)

Species	Indicator	Limit Derived from Chondrites (μg/g [%])	TAGSAM Surface Limit Requirement (ng/cm^2)
Amino Acids	Biological contaminant, special for astrobiology	20 [30%]	180
Hydrazine	Reduces organics	nd	180
C	Organics	32 [10%]	1000
K	Lithophile	5.4 [1%]	170
Ni	Siderophile	1100 [10%]	34,000
Sn	Industrial contaminant	0.017 [1%]	0.53
Nd	Lanthanide lithophile	0.047 [1%]	1.5
Pb	Chalcophile, special for chronology	0.025 [1%]	0.79

Still too many species to verify during Assembly Test and Launch Operations (ATLO) on critical surfaces: TAGSAM head, TAGSAM launch container, Sample Return Canister (SRC)

Translating Science to Engineering

We converted the science derived contamination control concentrations to the engineering standard, IEST-STD-CC1246D, assuming the worse-than-worst case assumptions that all particles and films are pure elements.

Particle Results

worst case

Measured in bins of maximum particle size for theoretical IEST-STD-CC1246D

Particle Level	Graphite (ng/cm²)
level 25	0.20
level 50	2.43
level 100	33.8
level 200	556
level 500	40230

Particle Level	Lead (ng/cm²)
level 25	1.1
level 50	13
level 100	182
level 200	2996

Film Results

worst case

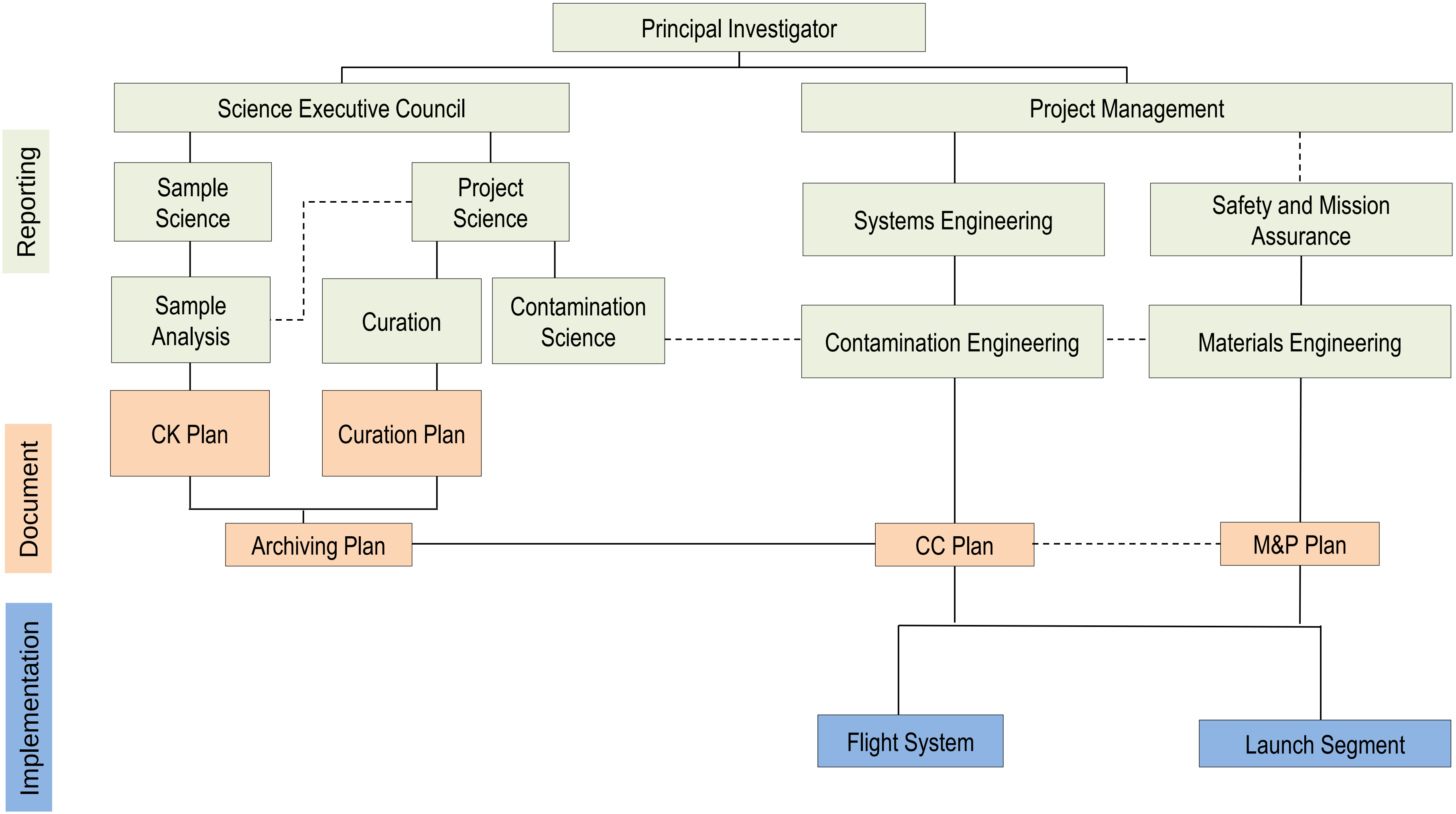
Measured in fractions of A of non-volatile residue.

Since the testing method produces a mass/area² the conversion is not based on density of material.

level	mg/dm²	µg/cm²	ng/cm²
B	2	2	2000
A	1	1	1000
A/2	0.5	0.5	500
A/5	0.2	0.2	200
A/10	0.1	0.1	100
A/100	0.01	0.01	10
AA3	0.001	0.001	1

100 A/2 + 180 ng/cm² amino acids achieves our science CC requirements except in pathological cases

OSIRIS-REx Contamination Organization

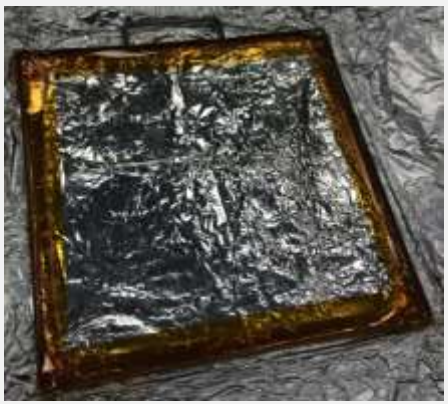


Documenting Contamination

Monitoring in Cleanroom

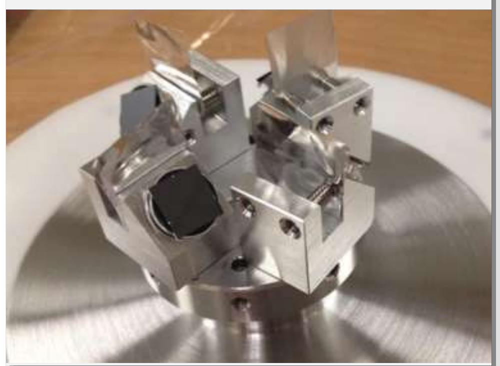
Contamination Control (CC)

Particle counts
Film thickness
Amino acids



Contamination Knowledge (CK)

Inorganic chemistry
Organic chemistry
DNA sequencing
& for future study



Monitoring on TAGSAM & SRC (CK)

For study after return

Gas and Fuel Analysis (CK)

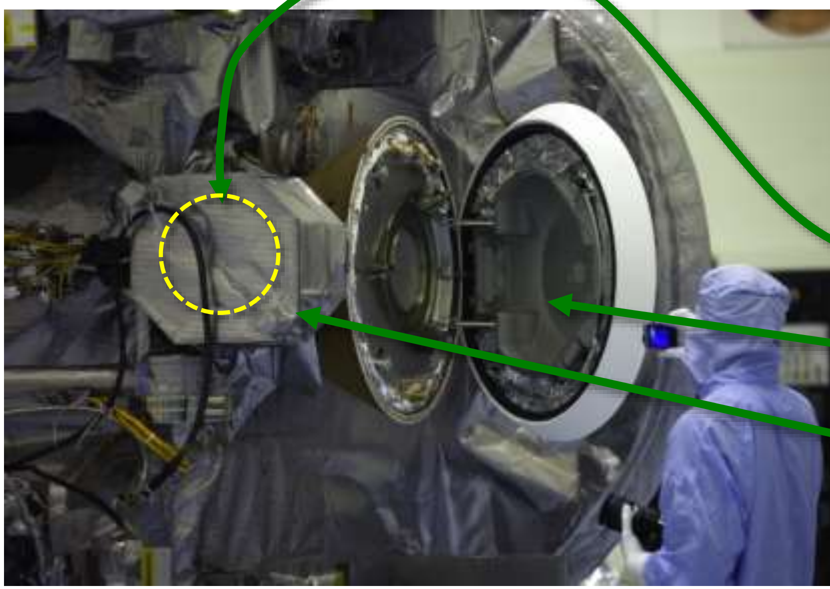
Samples of gases and fuel for trace organics and metals

Materials Archive (CK)

≥ 1 g of required materials of potential concern for archive and future study

Translating Engineering Back to Science

100 A/2 + 180 ng/cm² amino acids achieves our science CC requirements except in pathological cases



Surface	Amino Acids	Carbon (from 100 A/2)	K, Ni, Sn, Nd, Pb
Requirement	**180** ng/cm^2	**1000** ng/cm^2	**Anomalies?**
G TAGSAM Head	0.96	281	No
G SRC	13.1	503	No
G Launch Container	2.32	134	No

Contamination Knowledge demonstrated the lack of pathological cases

GSFC Lab analyses showed outstanding amino acid performance

LM analyses showed NVR and Particulate below carbon requirements

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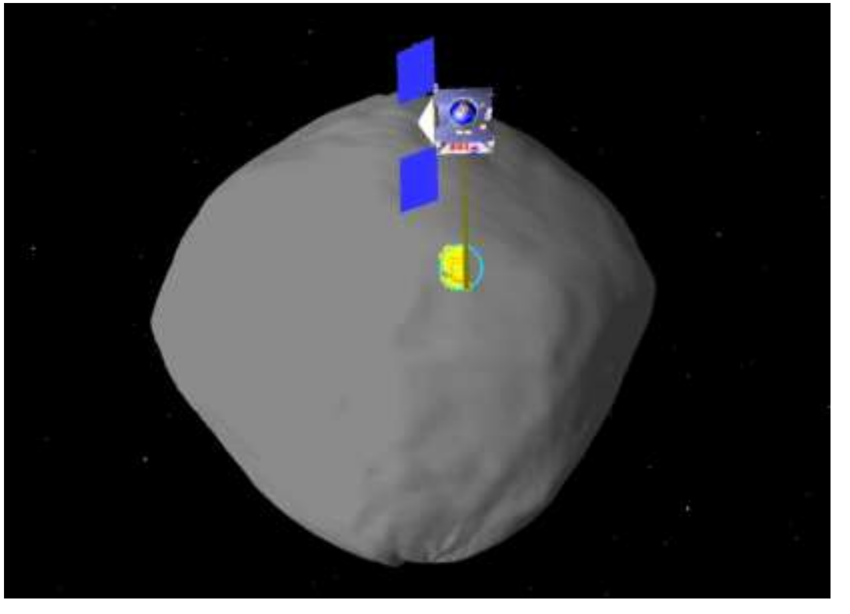

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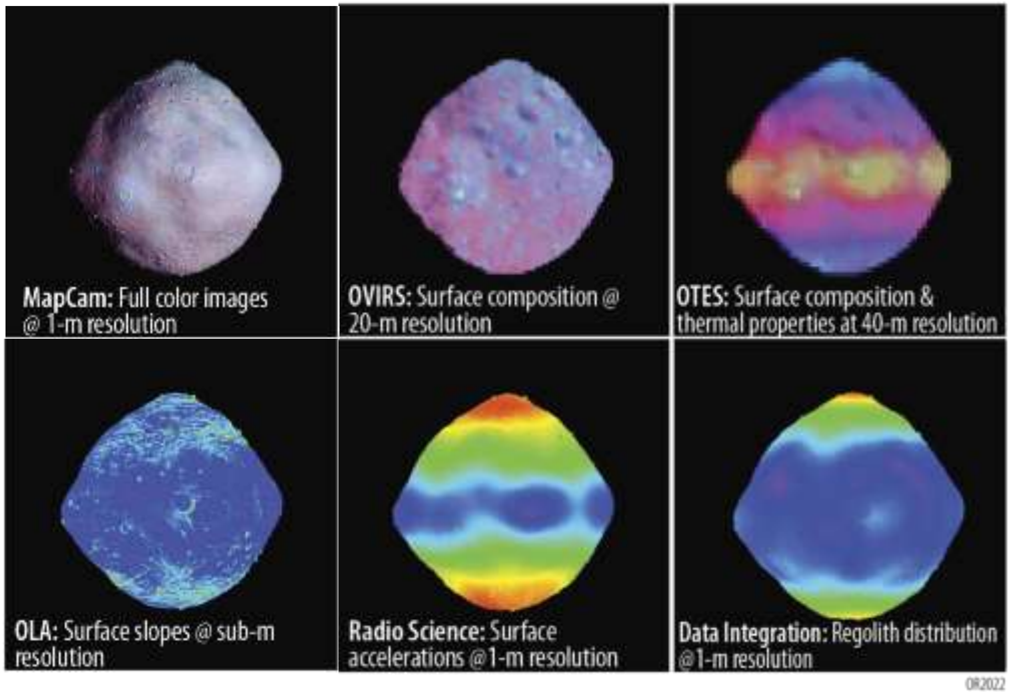

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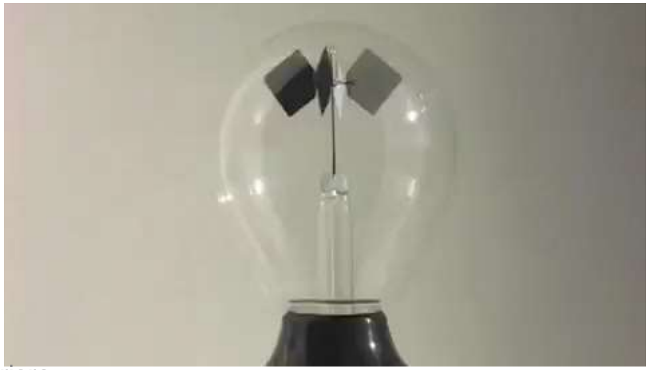

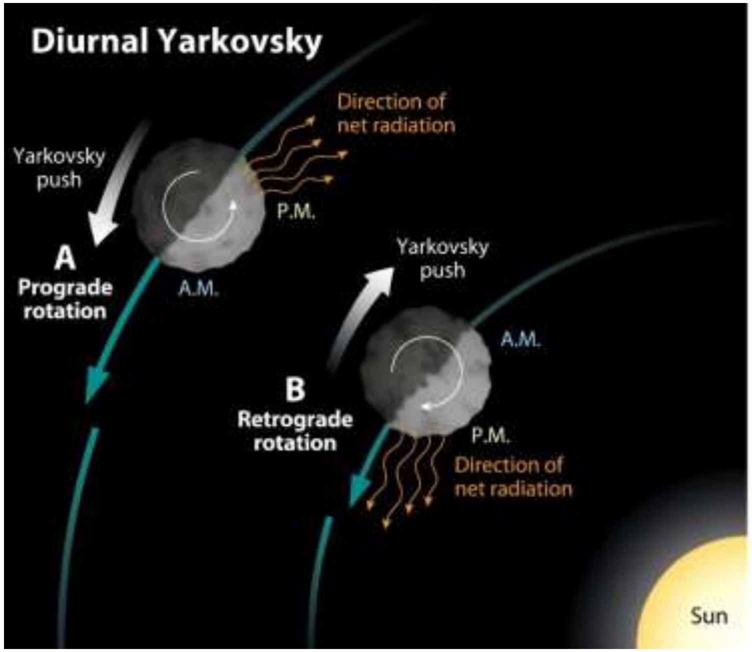

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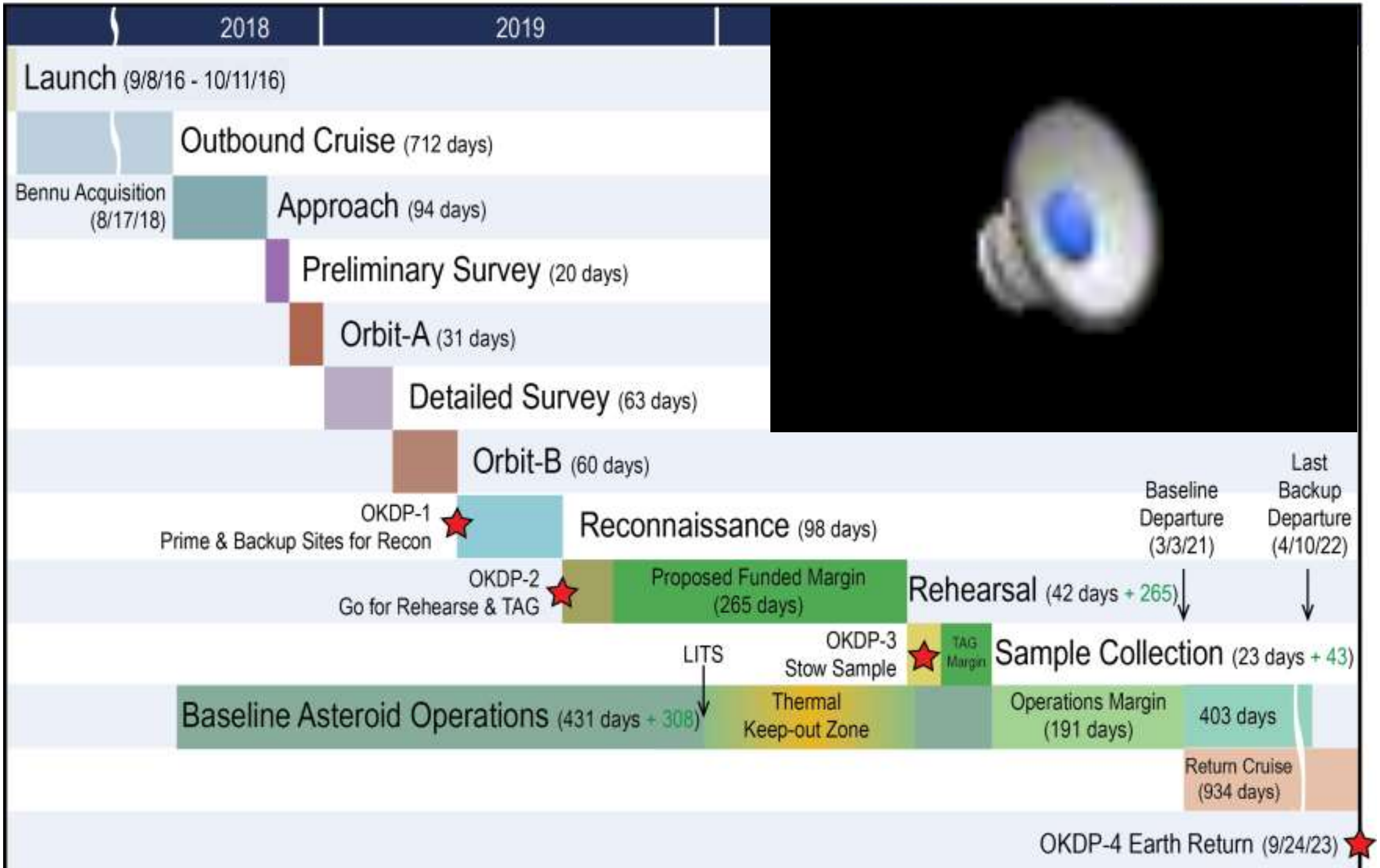
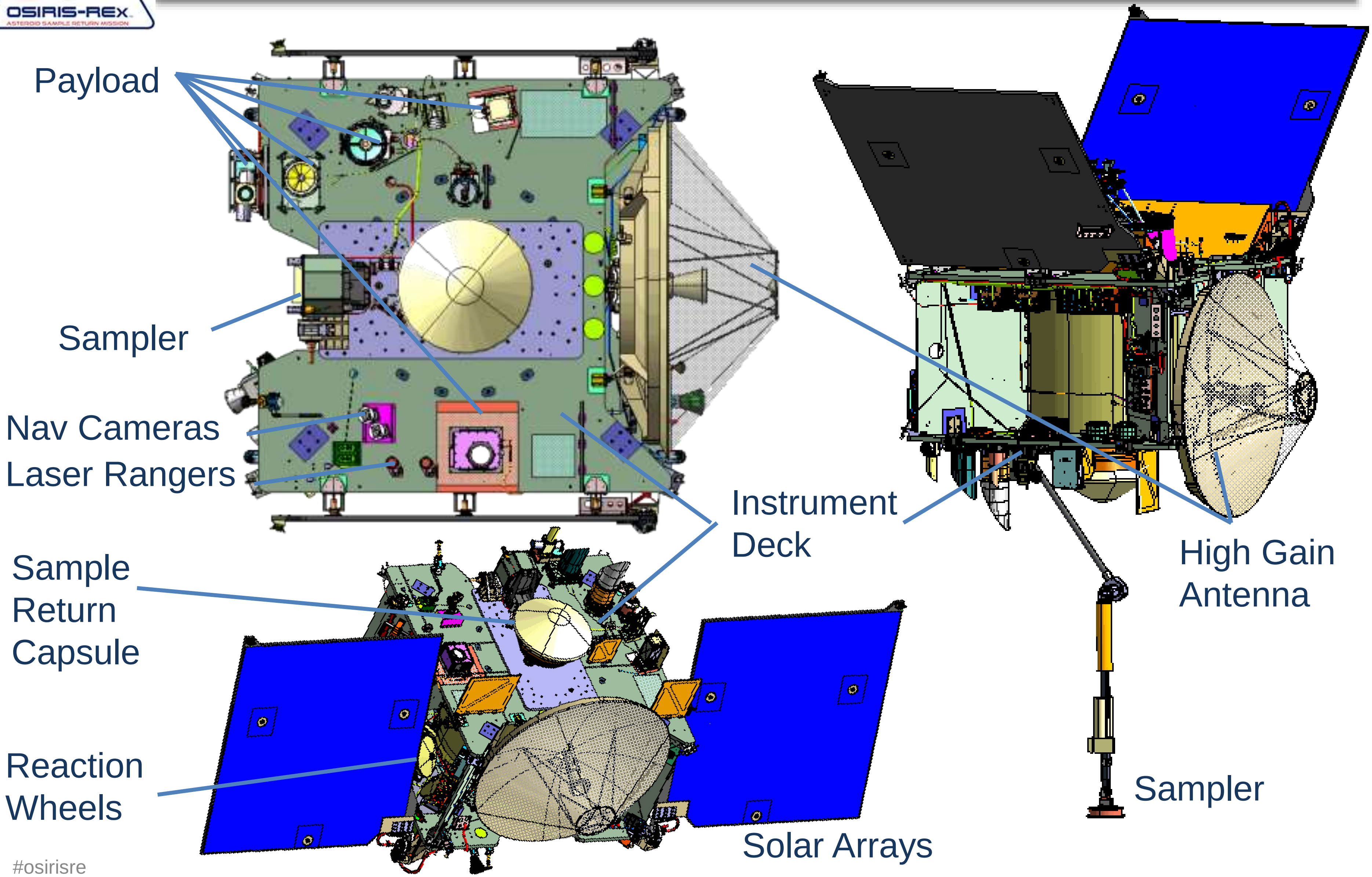
OSIRIS-REx Mission Plan



SPACECRAFT



#osirisrex

Instruments Place the Sample in Context

OVIRS (GSFC) maps the reflectance albedo and spectra from 0.4 – 4.3 µm

OTES (ASU) maps the thermal flux and spectra from 5 – 50 µm

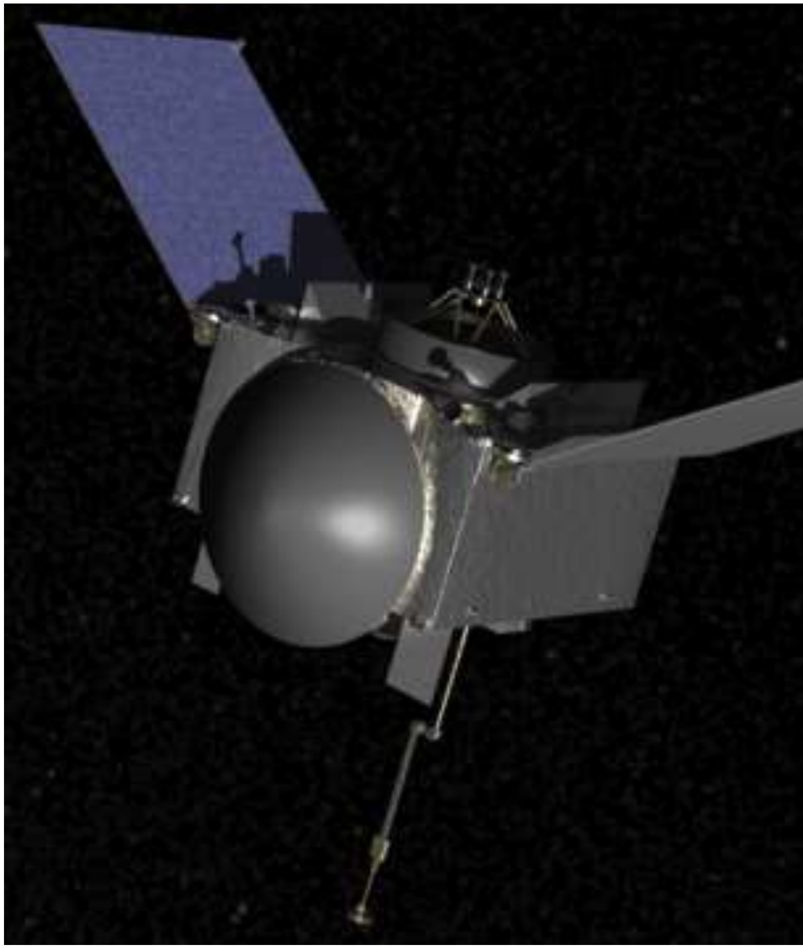
OCAMS (UA) **PolyCam** >500K-km range, high-resolution imaging of the surface, **SamCam** images the sample site and TAG, **MapCam** provides landmark-tracking, filter photometry.

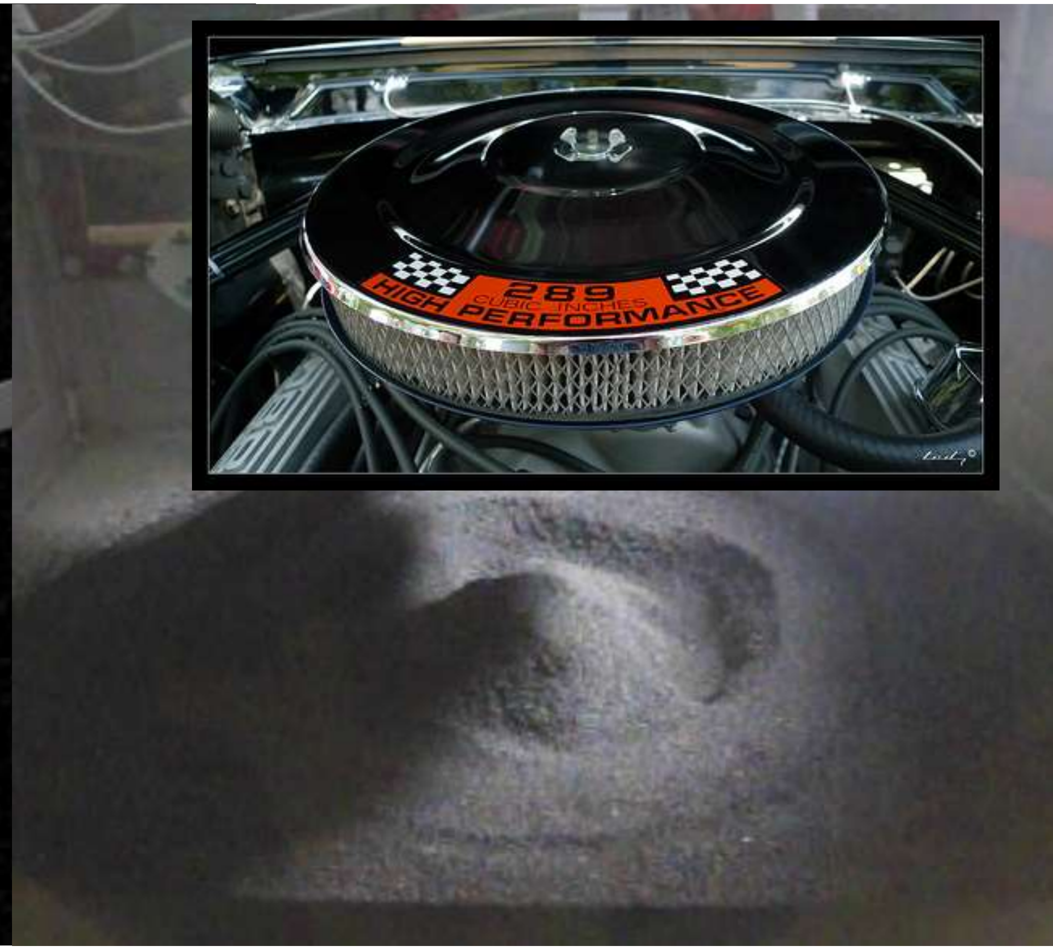
OLA (CSA) ranging to 7 km and maps the asteroid shape and surface topography

REXIS (MIT) Student Experiment maps the elemental abundances

Radio Science (CU) reveals the mass, gravity field, internal structure, and surface acceleration distribution

SAMPLE COLLECTION SYSTEM: TAGSAM





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SAMPLING SYSTEM: BUILT AND TESTED

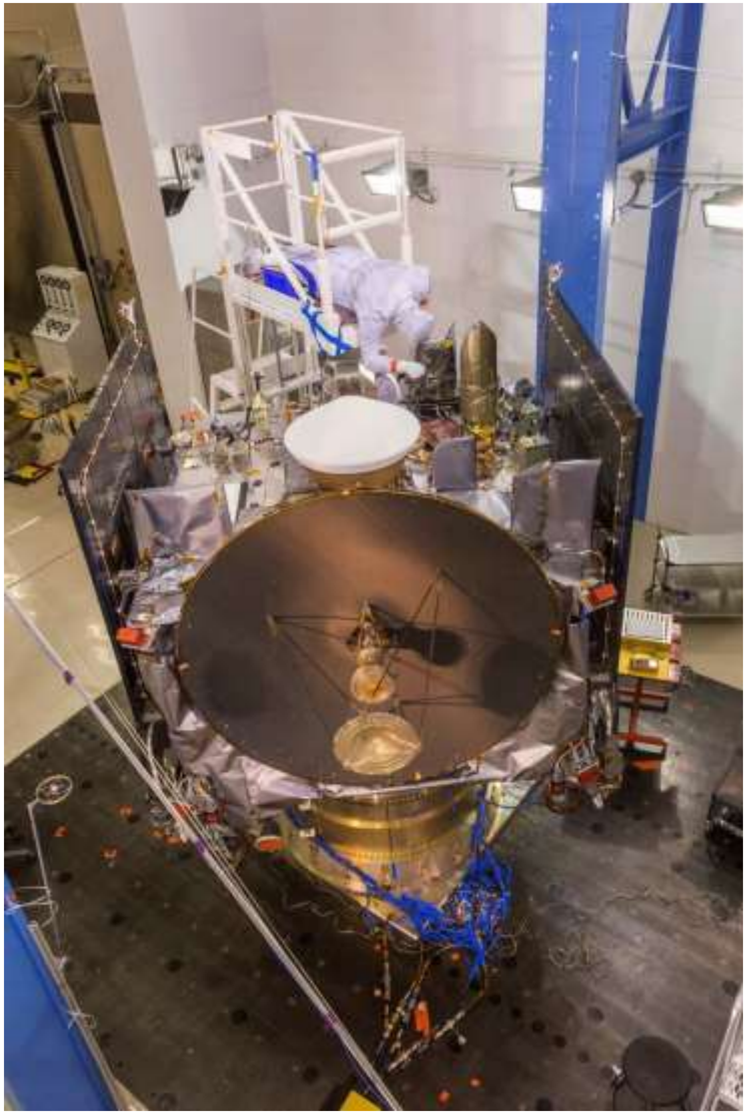
TAGSAM Test On Air Bearing
With Simulated Spacecraft

TAGSAM Test with Microgravity

TAGSAM Stow On Air Bearing
With Simulated Spacecraft

SRC Stow Testing
On Spacecraft

FLIGHT SYSTEM: BUILT AND TESTED



Test Like You Fly

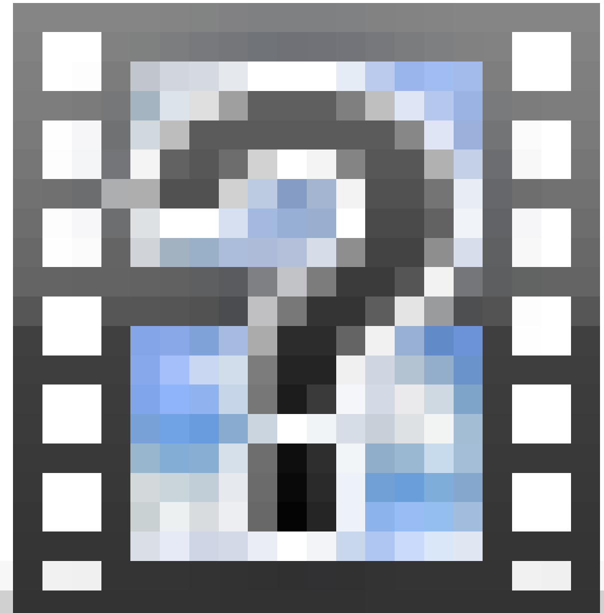
TEST LIKE YOU FLY

OSIRIS-REx Development

Discovery 11 Proposal	July 16, 2004
Non-selection	Feb 2, 2005
Discovery 12 Proposal	Mar 27, 2006
Down Select (KDP-A)	Oct 30, 2006
Step 2 Proposal	June 20, 2007
Site Visit	Aug 21, 2007
Non-selection	Dec 11, 2007
✓ New Frontiers 3 Proposal	July 31, 2009
✓ Down Select (KDP-A)	Dec 17, 2009
✓ Step 2 Proposal	Jan 28, 2011
✓ Site Visit	Apr 14, 2011
✓ Selection (KDP-B)	May 25, 2011
✓ MDR	May 8 – 10, 2012
✓ PDR	Mar 4 – 8, 2013
✓ Confirmation (KDP-C)	June 1, 2013
✓ CDR (KDP-D)	Apr 1 – 9, 2014
✓ SIR	Feb 24 – 27, 2015

OSIRIS-REx Implementation

✓ Start of ATLO	March 23, 2015
✓ PER	Oct 14 – 16, 2015
✓ Modal Survey	Oct 19 – 23
✓ Acoustics	Nov 3
✓ PLA Shock	Nov 6
✓ Sine Vibe	Nov 16 – 24
✓ S/A Release & Shock	Dec 3 – 4
✓ EMI / EMC	Jan 25 – Feb 3, 2016
✓ Thermal Vac	Feb 18 – Mar 10
✓ PSR	May 10 – 11
✓ Ship to KSC	May 20
✓ FOR / ORR	Jun 21 – 24
✓ SMSR	Aug 9
✓ MRB / KDP-E	Aug 18
✓ FRR	Sep 1
✓ LRR	Sep 6
✓ Launch	Sep 8: **On time and under budget!**



Thermal Vac Testing

Construction

Ship to KSC

OSIRIS-REx Launch

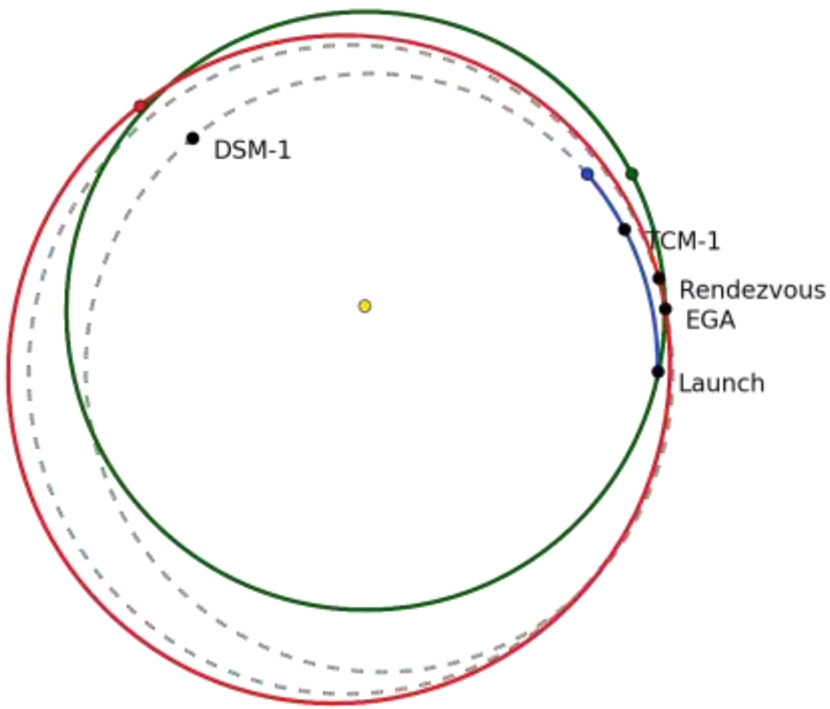
Launch 180ms into 7:05pm EDT window
September 8, 2016
SLC-41, Cape Canaveral

Atlas V 411
C_3 = 29.3 km^2/s^2

s/c wet mass = 2104.2 kg
s/c dry mass = 900.5 kg

fuel load 1199.9 kg N_2H_4
3.8 kg He pressurant

OSIRIS-REx Status



Current Values
19-OCT-2016 12:00:00 UTC

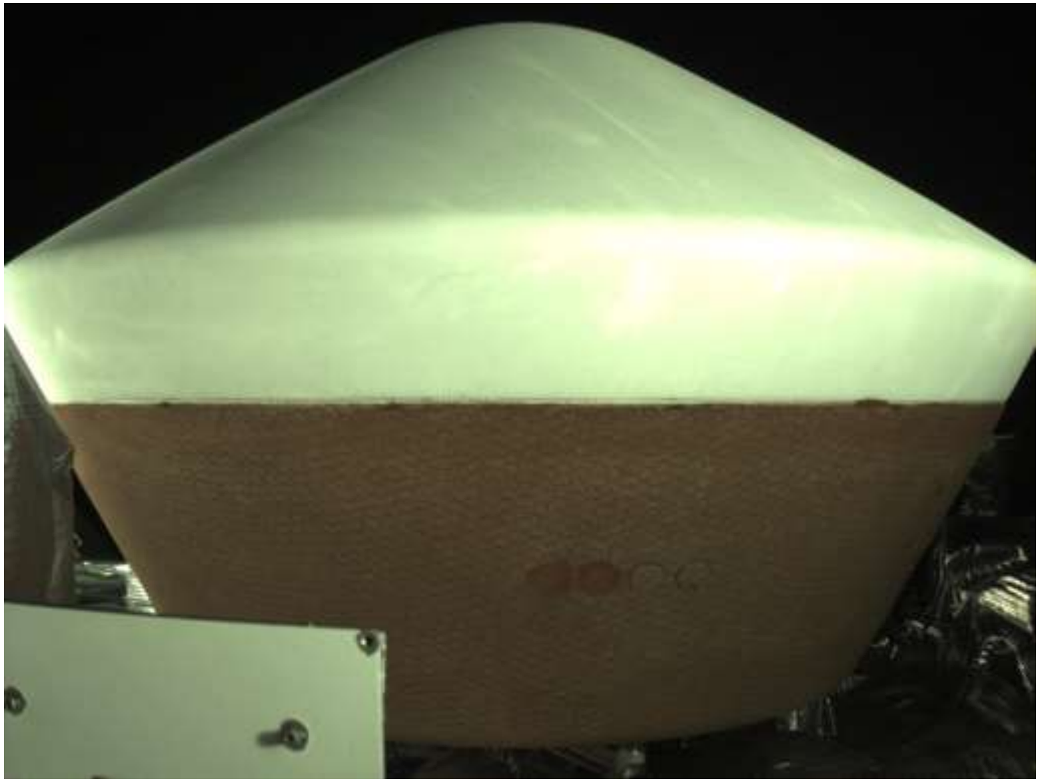
Total Distance traveled	1.09E+08	km
Distance till Rendezvous	1.88E+09	km
Distance to Earth	2.24E+07	km
Distance to Sun	0.865	AU
Speed relative to Earth	8.32	km/sec
Speed relative to SSB	33.7	km/sec
One-way Light Time	74.7	sec

All major subsystems have been tested and are performing nominally

OSIRIS-REx Status

All instruments have been powered on for initial checkouts and are currently all powered off

Instrument	Status
OCAMS: PolyCam	G
OCAMS: MapCam	G
OCAMS: SamCam	G
OVIRS (A/B)	G
OTES	G
OLA (high/low)	G
REXIS (and SXM)	G



StowCam Image
L+14 days

JOIN THE MISSION ON THE WEB!

AsteroidMission.org

DSLauretta.com

OSIRISREx

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+OSIRISRExMission